# ULTRASTABLE REFERENCE FREQUENCY DISTRIBUTION UTILIZING A FIBER OPTIC LINK*

**MALCOLM CALHOUN and PAUL KUHNLE**
**California Institute of Technology**
**Jet Propulsion Laboratory**
**Pasadena, California 91109**

**Abstract**

*The Frequency Standards Laboratory at the Jet Propulsion Laboratory (JPL) is responsible for the generation and distribution of ultra-stable reference frequency in NASA's Deep Space Network (DSN). Certain assemblies and components of the Radio Science and VLBI systems are located in the cones of tracking antennas hudreds of meters from the Frequency and Timing Subsystem's frequency standards. The very stringent requirements of these users challenge the performance of state-of-the-art frequency sources as well as the associated signal distribution system. The reference frequency distribution system described in this paper is designed around a low temperature coefficient of delay (TCD) optical fiber. On-site measurements of the fiber optic link alone indicate 100 MHz phase noise performance on the order of -120 dBc at 1 Hz from the carrier and Allan deviation on the order of parts in $10^{16}$ at 1000 seconds averaging time. The measured phase noise and stability of the link indicate that the performance characteristics of the hydrogen maser frequency standards are not degraded by the distribution system. Thus, optical fibers and electro-optic devices as distribution media appear to be a viable alternative to the classical coaxial cable distribution systems.*

## INTRODUCTION

Reference signals for Radio Science experiments in the NASA/JPL Deep Space Network are provided by hydrogen masers. These masers are located centrally at the DSN tracking stations in a controlled environment. The signals which drive the Radio Science local oscillators and up/down convertors must maintain maser quality for equipment which is located hundreds of meters from the maser source and in an environment which subjects this equipment to temperature variations as well as vibration. Cable runs from the base of the antennas to the cone areas may be exposed to a temperature differential as great as 40° C over a twelve hour period. Additionally, the equipment located in the antenna is subjected to mechanical vibration and flexing of the cables. Reference

*This work represents one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract sponsored by the National Aeronautics and Space Administration.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE<br>**DEC 1992** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-1992 to 00-00-1992** |
| 4. TITLE AND SUBTITLE<br>**Ultrastable Reference Frequency Distribution Utilizing a Fiber Optic Link** | | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**California Institute of Technology,Jet Propulsion Laboratory,Pasadena,CA,91109** | | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | 10. SPONSOR/MONITOR'S ACRONYM(S)<br>11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES
**See also ADA267301. 24th Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, McLean, VA, 1-3 Dec 1992**

14. ABSTRACT
**see report**

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **7** | |

frequency distribution via coaxial cable does not provide the required stability at the point of use for some of the more sophisticated deep space investigations such as very long–base interferometry (VLBI), gravity waves, and planetary rings and occultation experiments. This paper describes a reference frequency distribution scheme which has proven to be a successful alternative to methods used previously. The new distribution system is based upon a single–mode fiber optic link employing a temperature compensated fiber along with state–of–the–art electro–optic devices. The fiber optic reference frequency distribution has been installed and tested at two DSN antennas and is scheduled for installation at four more locations.

## DESIGN APPROACH

The terminal equipment hardware in the distribution links consists of single–mode laser transmitters located near the frequency standards in the DSN Signal Processing Center (SPC); compatible fiber optic receivers are located at the antennas near or in the cone areas. In addition to the optical transmitters and receivers, operational requirements dictate that certain critical system parameters be monitored and made available to DSN operations personnel at the SPC. Figure 1 is a block diagram of the fiber optic reference frequency distribution assembly showimg the major subassemblies and their locations.

A 100 MHz reference frequency signal derived from the station's primary frequency standard (typically, a hydrogen maser) is applied to the fiber optic transmitter unit. The 100 MHz signal is applied to a laser diode through a rf matching network where the light intensity is varied by direct intensity modulation. The principal component of the transmitter is a single–mode, distributed feedback (DFB) laser diode with an integral optical isolator [1]. The laser is commercially available as a modular unit including bias circuitry and temperature control. A second optical isolator external to the laser provides approximately 60 dB isolation to prevent optical back–reflection from degrading the laser performance. The laser emits light at 1300 nm which is launched into a single–mode optical fiber; optical interfaces between the system optical fiber and the transmitter and receiver employ slant–polished connectors to reduce back reflection. The rack–mounted fiber optic transmitter along with the monitor interface and monitor computer are located in the control room of the SPC.

The fiber optic receiver is located several hundred meters from the transmitter in the cone area of the antenna. The photodetector in the receiver is optically matched to the 1300 nm light signal from the transmitter. The impinging 1300 nm light is converted from optical to 100 MHz rf at the p–i–n photodetector. The optical loss over the fiber between the transmitter and receiver typically is less than 1 dB, thus care must be exercised to prevent overdriving the photodetector. An optical attenuator located in the transmitter unit is set so that the received optical power is approximately 1 mW, resulting in -30 dBm of at the photodiode output. A low–noise rf pre-amplifier is employed to raise the signal to a higher level for subsequent distribution to users. A low–pass filter is used to mitigate any non–linear effects of the laser diode and photodetector. Typically, second and third harmonics of the 100 MHz output signal are 45 dB or more below the fundamental. The 100 MHz reference signals to the users are distributed through low–noise power amplifiers which provide greater than 100 dB isolation between output ports. Temperature control has been provided at the receiver since the antenna location is subject to variations in temperature. A

Peltier temperature device, temperature sensor, and control circuit provide a factor of twenty–five times reduction in ambient temperature effects. The optical receiver and the rf distribution circuits are contained within an emi/rfi shielded box to prevent stray rf radiation and/or magnetic fields from corrupting the 100 MHz signal. Measurements made in the field indicate that the distributed reference signals are virtually free of non–harmonic spurious signals including power line related frequencies.

Power supplies for the fiber optic receiver assembly are located in a separate emi/rfi shield box to isolate them from the receiver. The power supply assembly also houses the data acquisition circuits for the monitor functions. Monitor signals are feed from the antenna to the SPC via multi–mode fiber optic modems.

## DISTRIBUTION SYSTEM OPTICAL FIBER

The longest run of fiber optic cable in the network is approximately 800 meters. Surface temperature variations at the stations are so great that exposed cable trays cannot be used for reference frequency distribution cable runs. In order to minimize phase variations due to temperature effects on the cable, the optical fiber cable run is in a duct which is underground at a depth of 1.5 meters. Temperature profiles of the ground near the antenna indicate that at this depth the cable is not affected by diurnal variations in temperature; however, seasonal effects are observed. The cable run from the base of the antenna to the cone area is exposed to the maximum outside temperature variation. This cable run is between 50 and 70 meters in length.

The optical fiber used in this distribution system is a special commercial fiber which has been treated to reduce the temperature coefficient of delay (TCD). Measurements in the laboratory indicate that the TCD of this particular fiber is approximately 0.3 ppm/°C for temperatures below 25°C and less than 1 ppm/°C in the range from 25°C to 35°C **[2]**. The TCD of typical commercial optical fiber is approximately 7 ppm/°C while the coaxial lines used presently for reference distribution are 15 ppm/°C or greater. Thus, the special low TCD optical fiber performs very well in locations where there are extremes of temperature such as exposed cable runs on the antennas. Figures 2 and 3 show results of tests using the low TCD optical fiber under operating conditions at DSS 14. The test period for the data shown in the figures is three days. Figure 2 shows the actual phase variation at 100 MHz. Stability test results are shown in the Sigma–Tau plot of Figure 3. The hump in the Allan deviation is due to the diurnal temperature variations. Note that the 1000 second Allan deviation is just slightly greater than 1 part in $10^{16}$. During this test, surface temperature variations were 30°C peak–to–peak over a twelve hour period.

## LINK PERFORMANCE RESULTS

Following installation of the fiber optic distribution equipment and cables at Deep Space Station 15 (DSS 15) and Deep Space Station 45 (DSS 45) extensive testing was done to verify that system requirements were satisfied. Figure 4 is a graph of phase noise spectral density at DSS 15. The single–sideband power spectral density at 1 Hz from the carrier frequency of 100 MHz is -120 dBc with a floor of -140 dBc; the Radio Science System requirement at the receiver first local oscillator is -92 dBc with a floor of -125 dBc. Thus, the fiber optic reference frequency distribution does not

degrade the noise performance of the reference signal from the hydrogen maser.

Figure 4 is a plot of Allan deviation for the same distribution link. It is worth noting that a second test link from the antenna to the SPC was employed in order to measure Allan deviation and phase noise since there is no better quality reference signal available at the antenna. The test link carries the reference signal from the distribution amplifier at the output of the receiver in the antenna back to the reference maser at the SPC. Thus, the actual stability of the reference signal as graphed in Figure 4 is better by at least 3 dB due to the extra test link used. Stability measured at 1000 and 3600 seconds indicate approximately 2 parts in $10^{16}$ which is an order of magnitude lower than Radio Science System requirements.

## SUMMARY

Fiber optic reference frequency distribution installations at two of six DSN stations are complete with the remaining four to be installed in 1993. Low TCD optical fiber must be employed in the link to meet stability requirements. The bulk of the cable run between the SPC and the antenna is underground at a depth of 1.5 meters. An alternative to the low TCD optical fiber is active phase stabilization of the fiber links [3]. Test results indicate that fiber optic reference frequency distribution is superior to coaxial cable and that stability and noise performance requirements for very sophisticated radio science experiments can be met.

## REFERENCES


[1] Operator's Manual, Model 3612B Laser Transmitter, ORTEL Cororation

[2] Data Heet #88-31 supplied to Jet Propulsion Laboratory by Sumitomo Electric Industries, Inc, June 1, 1988

[3] D. Johnson , M. Calhoun, R. Sydnor, and G. Lutes, "A Wide-band Fiber Optic Frequency Distribution System Employing Thermally Controlled Phase Compensation," Proceedings 24th Annual Precise Time and Time Interval Applications and Planning Meeting, December 1992.

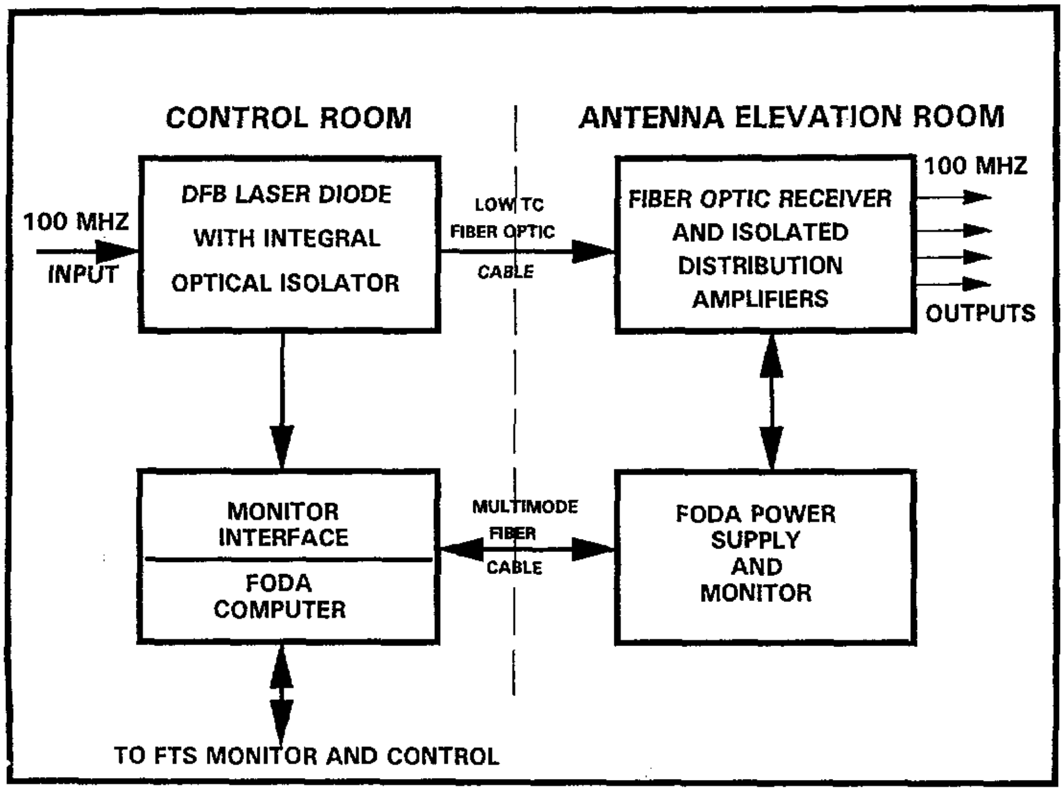


Figure 1. Block Diagram, Fiber Optic Reference Frequency Distribution Assembly

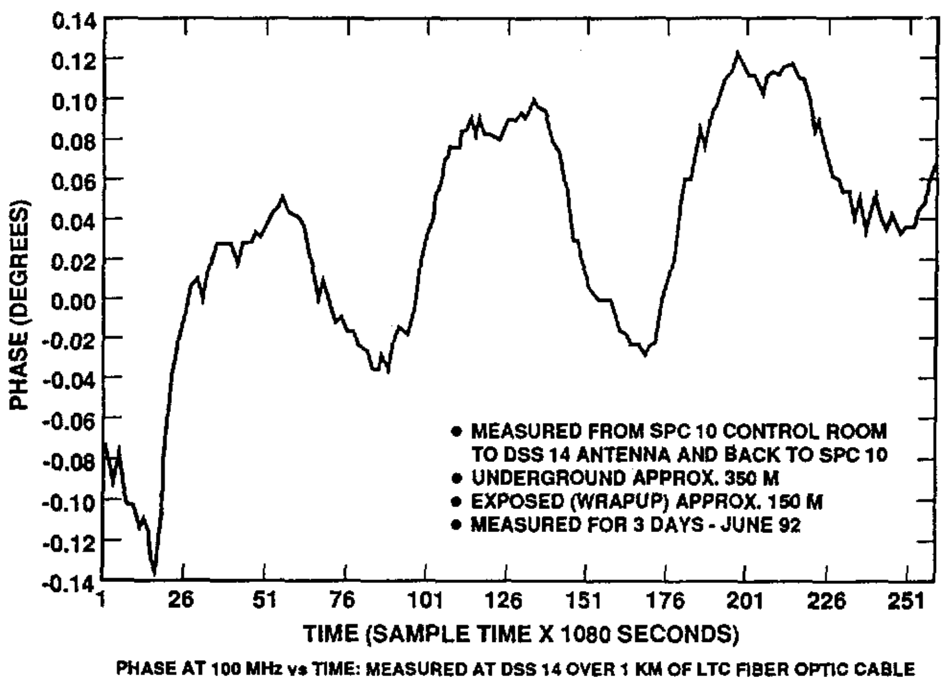


Figure 2. Phase Variations at 100 MHz Over Low TCD Optical Fiber

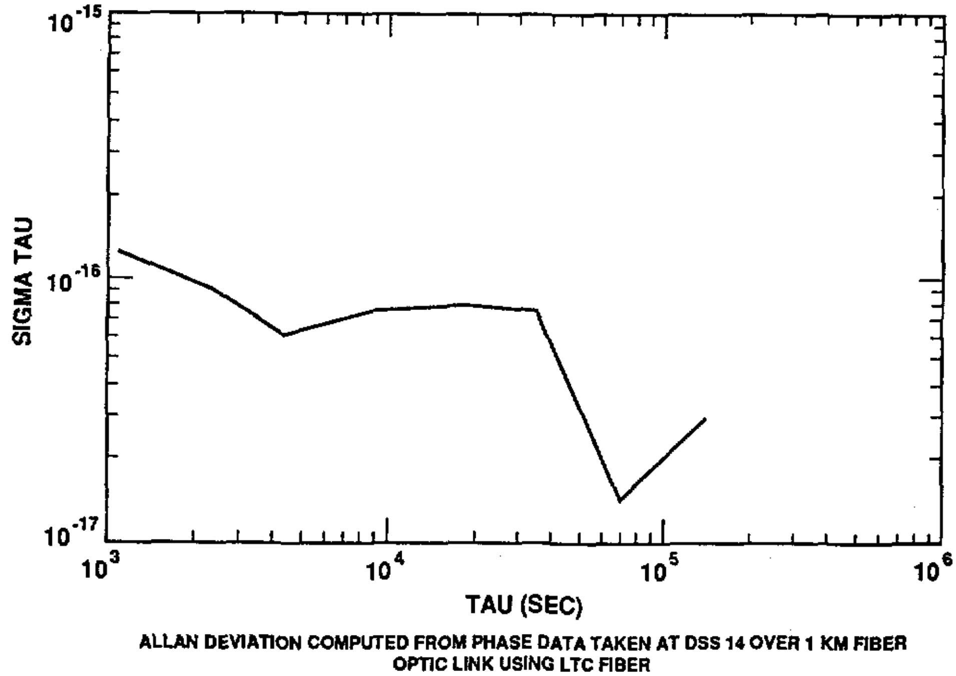


Figure 3. Allan Deviation of Low TCD Optical Fiber

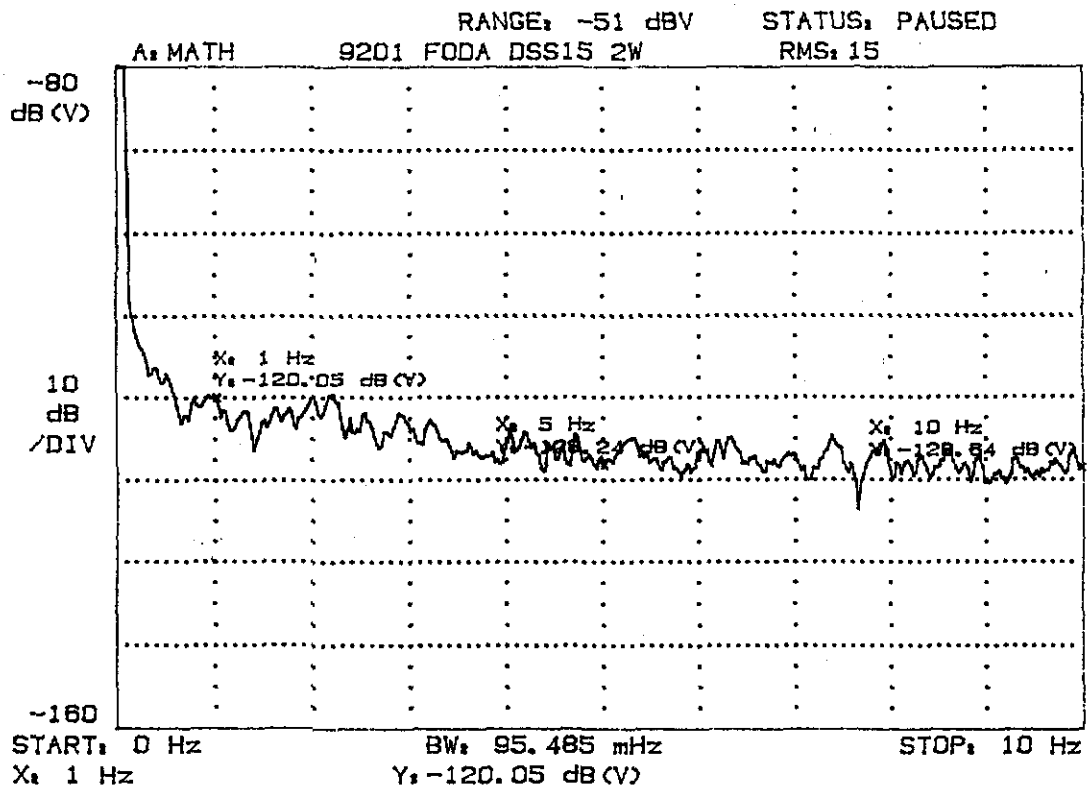


Figure 4. Phase Noise Density Measured Over Fiber Optic Reference Frequency Distribution

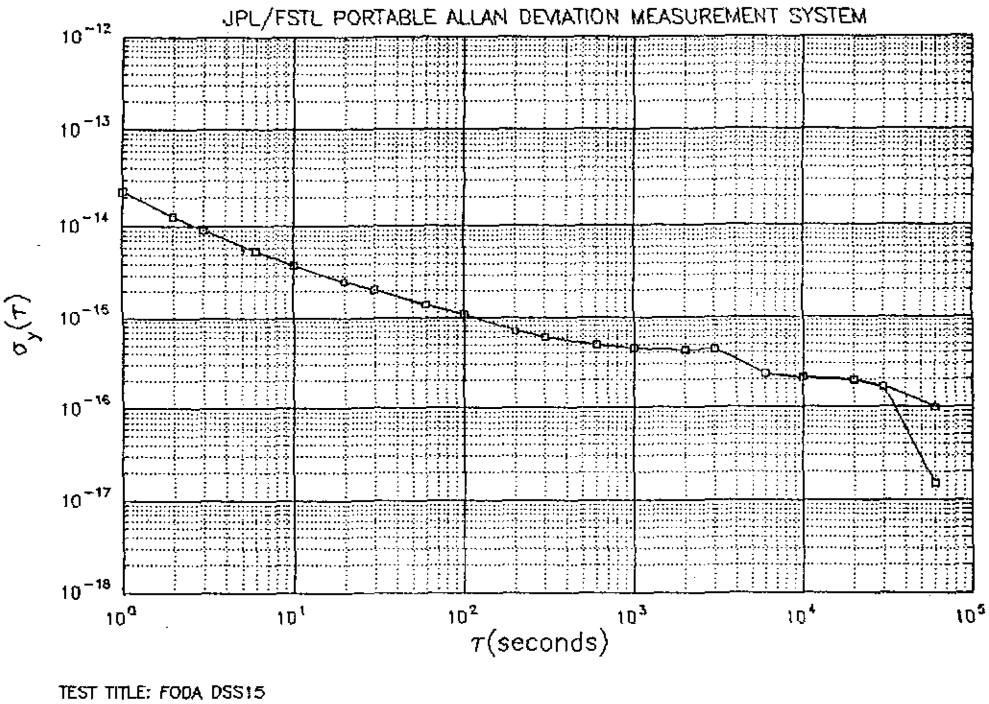


**Figure 5. Allan Deviation Measured Over Fiber Optic Reference Frequency Distribution**